MC3E field campaign
Radar sampling strategies

Drafted by:

Pavlos Kollias[1], Steven Rutledge[2], Scott Giangrande[3], Walter Petersen[4]
Scott Collis[5] and Nitin Bharadwaj[6]

1.McGill University, 2. Colorado State University
3.Brookhaven National Laboratory, 4. NASA Marshall Space Flight Center
5. Argonne National Laboratory 6. Pacific Northwest National Laboratory

1. Introduction

The Midlatitude Continental Convective Cloud Experiment (MC3E) represents a collaborative effort between the NASA Global Precipitation Mission (GPM) ground validation (GV) and the Department of Energy (DOE) Atmospheric Systems Research programs. The experiment will take place in south-central Oklahoma, centered at the DOE ARM SGP facility during the April-June 2011 period. The goal of the MC3E is to provide a complete characterization of convective cloud systems and their environment. This data set will be used for many applications including providing constraints for model cumulus parameterizations, and physical validation of NASA GPM precipitation algorithms currently under development. Several different components of convective processes tangible to the convective parameterization problem and the remote sensing of precipitation are targeted such as, pre-convective environment and convective initiation, updraft / downdraft dynamics, condensate transport and detrainment, precipitation and cloud microphysics, influence on the environment and radiation. Also a detailed description of the large-scale forcing will be obtained.

The intensive observation period will use a new multi-scale, multi-wavelength observing strategy with the participation of a network of distributed sensors (both passive and active). The approach is to document in 3-D not only precipitation, but also clouds, winds and moisture in an attempt to provide a holistic view of convective cloud systems and their feedback with the environment. A central goal for the DOE component is to measure cloud and precipitation transitions and environmental quantities that are important for convective parameterization in large-scale models and cloud-resolving model simulations. With unprecedented observing capabilities comes a greater responsibility to develop synthesis data products suitable for model studies and evaluation. Thus, special emphasis is given to the development of a systematic dialogue with the ARM modeling group for the development of such 3-D data products. The central goal of the NASA component is to provide for a physical characterization of clouds and precipitation, consisting of both remote and in-situ sampling in order to validate physically-based assumptions used in GPM precipitation retrieval algorithms.

2. MC3E ground-based radar facilities

The joint NASA/DOE MC3E field campaign will bring together unprecedented radar resources to the ARM SGP Central Facility (CF).

2.1. NASA/GPM radar systems [cf. MC3E Science Plan for radar specifications]

The NASA GPM Ground Validation (GV) program will deploy the following radar resources as a complement to its other airborne and ground-based instrumentation in and around the ARM SGP facility during MC3E:

a. transportable 2.75 GHz (S-band) polarimetric Doppler radar (N-POL)

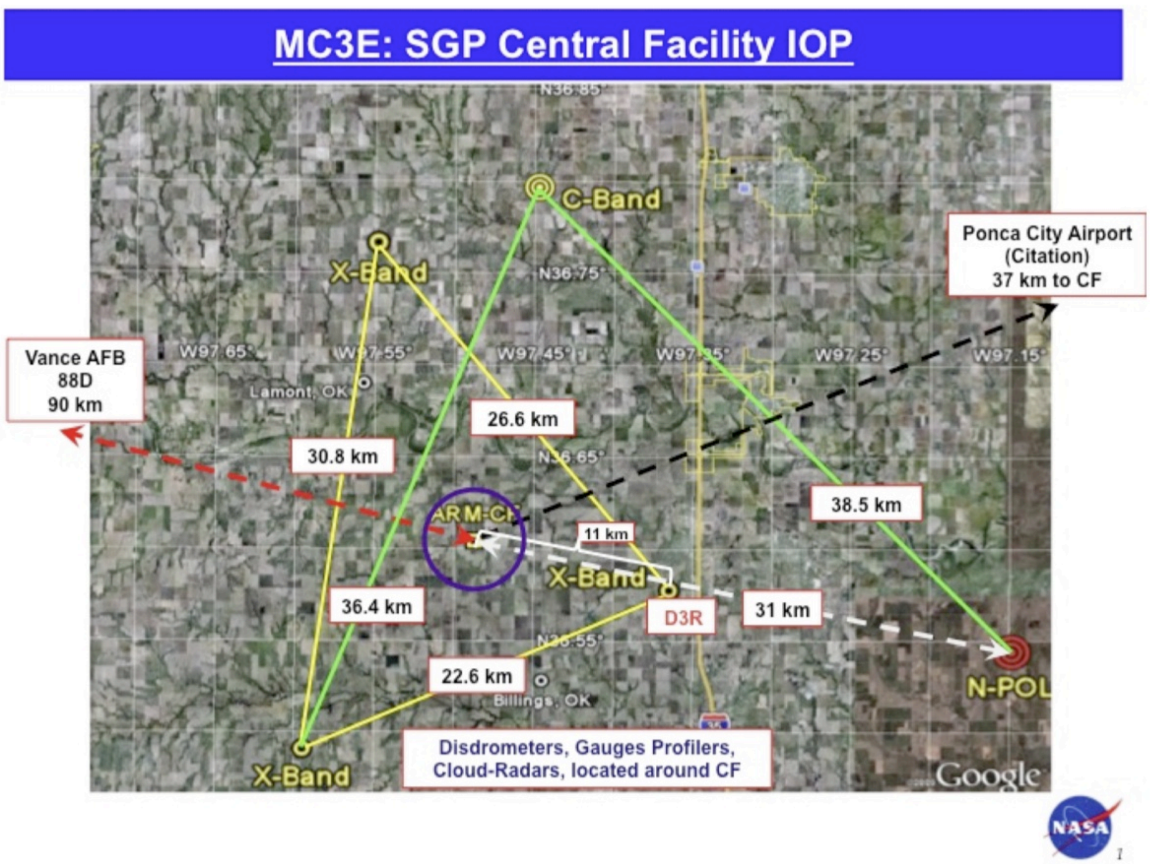
b. 35.7/13.4 GHz (Ka/Ku band] deployable dual-polarimetric Doppler scanning radar (D3R)
c. 2.7 GHz [S-band] profiler
d. 449 MHz [UHF] wind profiler

2.2. DOE/ARM radar systems [cf. MC3E Science Plan for radar specifications]

The backbone infrastructure of the ARM SGP radar facility is a distributed, heterogeneous network of profiling and scanning radar systems suitable for the mapping of cloud and precipitation in 3D along with a small network of radiometers and lidar systems.

The SGP radar facility includes:

a 5.4-GHz (C-band) scanning polarimetric weather radar,
a network of three 9.4-GHz (X-band) scanning polarimetric radars
a dual frequency (94/35-GHz) (W/Ka) scanning polarimetric cloud radar
a network of four 915-MHz wind profilers
a vertically pointing 35-GHz (Ka) cloud radar (MMCR)



Map showing the location of the ARM SGP Central Facility (CF, purple circle), the locations for the X-band Scanning ARM precipitation radars (X-band), the C-band scanning ARM precipitation radar, the NASA NPOL and D3R radars, the 915 MHz radar wind profilers (RWP), the dual- wavelength scanning cloud radar (Ka/W), and the S-band wind profiler (S).

3. NASA radar resources – radar scan strategies

During the MC3E field campaign the GPM/GV program has the following scientific objectives:

i) Obtain high resolution polarimetric observations for retrieving microphysical processes and precipitation, in relation to ER-2 aircraft radar and radiometer measurements for algorithm validation, and UND Citation II measurements for in-situ validation
ii) Retrieve kinematics and microphysical structures in a spectrum of convective systems for validation of cloud models.
iii) Diagnose 3-D, spatial and temporal characterization of DSD and rain rate variability within an area immediately surrounding SGP down to sub-footprint scales (i.e. , 1-10 km).

Due to the emphasis of the GPM/GV program on algorithm development and validation for the spaceborne GPM/DPR, two main classes of recommended radar scan strategies are discussed: those when research aircraft are in the vicinity of the ARM SGP CF and those when research aircraft are not flying in the vicinity of the SGP CF. NASA GV is mainly interested in documenting the structures of precipitating clouds. DOE operations and infrastructure extend this interest to non-precipitating clouds.

3.1. NASA radar scan strategies during aircraft flights

During aircraft flights, the objective of the radar scans is to support the development of the dual-profiling radar (DPR) and combined radiometer-DPR algorithms by providing microphysical retrievals (e.g., drop size distribution parameters, hydrometeor identification). Depending on the location of the storm and the aircraft flight patterns, the N-POL and D3R radars will perform either sector PPI scans or RHI's scans (if the interesting echo and aircraft racetracks are along the N-POL and D3R baseline; Figs 1-3). Here the emphasis is placed on high resolution sampling in the vertical dimension to quantify the vertical structure of precipitation properties. Priority will be given to cases where Citation II and ER-2 are able to fly stacked legs along the CF-NPOL radial (Fig. 3). N-POL will also need to do occasional sector volume scans to provide the most un-attenuated look at the precipitation to assess DSD and rain rate variability over the scene. The basic scan patterns that are proposed when aircraft are present are illustrated in Figs. 1 and 2 and a "dream" scenario for sampling along the CF-NPOL radial is shown in Fig. 3

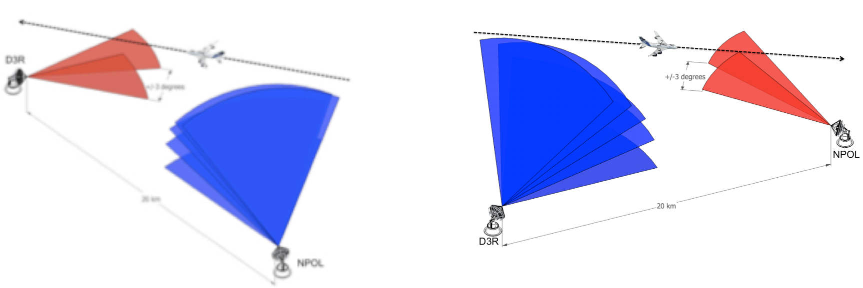


Fig 2. Aircraft flying radials from N-POL, then NPOL goes into narrow RHI sectors. D3R does volume sector scans to top the storm.

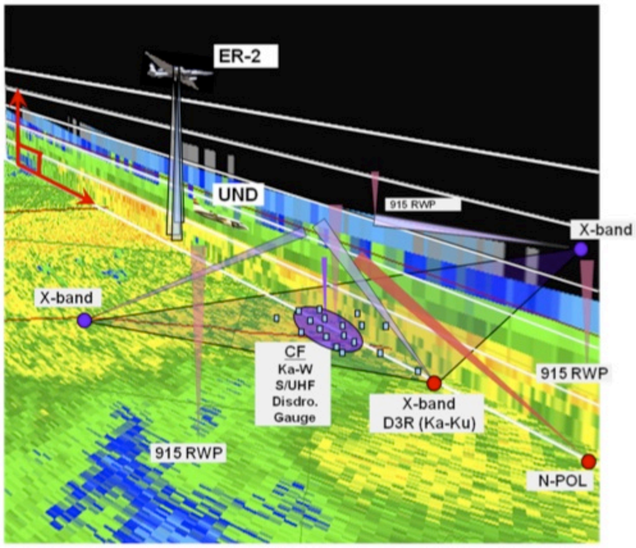


Fig. 3. Desired scenario for operations along radial from CF to NPOL radar with aircraft stack.

Note that when stratiform precipitation exists directly over the D3R and/or the NPOL radars and no flight operations are ongoing, occasional vertically-pointing ZDR calibration scans (e.g., "birdbaths") will be performed to document vertical structure.

3.2. NASA radar scan strategies during no aircraft flights

When aircraft are not present, the storm of interest will be scanned by both N-POL and D3R using variable width sectors that encompass the main echo. Three-dimensional volume scanning with the maximum temporal resolution will be used. These scans can also serve as the basis for doing high temporal resolution [4-D; time separation between scans of order 1-2 minute] narrow sector volume mapping of rainfall and DSD variability, especially when precipitation is located over the dense CF disdrometer network. When possible, several RHI's will also be coordinated between the DOE X-band and collocated D3R radars and the NPOL radars along the CF radial.

In order to further document DSD variability between the ground and melting level over the duration and wider domain of the field campaign N-POL will do a "rain scan" consisting of a 3 tilt, high resolution scan approximately every 10 minutes. Linear depolarization measurements will be required on this scan, hence N-POL will be operated in a staggered mode. This scan will be implemented in an automated mode to cover the SGP CF site. For more detailed microphysical investigations, the N-POL and D3R triplet can be punctuated with RHI's in echo of interest.

. In summary the operational strategy for N-POL is outlined in the following table:

Operational/Meteorological Condition	**Aircraft**	**N-POL scan strategy**
No precipitation in range	No	Low-level 360^{o} PPI's
Precipitation in range	No	5-min sector PPI (top 15 km MSL at 20 km) Can include select RHI sweeps
Large-scale (widespread) precipitation	Yes	Narrow sector RHIs along same radial as D3R (1-2 min)

		Aircraft fly stacked legs along radial
Isolated precipitation	Yes	Narrow sector RHIs following aircraft ER-2 overflies, Citation penetrates edges
Precipitation over gauge/disdrometer network - DSD variability	No	Narrow low-level PPI sectors, 2-3 RHI sweeps, alt H/V (1-2 min)

3.3 NASA Profiling radar strategy

A vertically-pointing S-band profiler (operating at 2.875 GHz) and a 449-MHz wind profiler locked in vertically-pointing mode will be deployed at the Central Facility near the MMCR (West of the MMCR, between the fence and the access road). The profiling systems will operate continuously during the experiment. Operating parameters for both profilers are listed in the Table below.

For the S-band profiler, the Doppler velocity power spectra will be recorded approximately every 2 seconds. The S-band profiler saturates at low altitudes when the reflectivity exceeds about 50 dBZ at 2 km. Therefore, the profiler will operate in two modes: a precipitation mode, and an attenuated mode. The operating parameters are the same for both modes, except that the attenuated mode has about 30 dB of attenuation added to the receive circuitry to prevent saturation. The S-band profiler will operate continuously in the precipitation mode for approximately 45 seconds and then in the attenuated mode for approximately 15 seconds.

The 449 MHz wind profiler will operate only in the vertically-pointing mode; i.e., no horizontal winds will be estimated with this wind profiler. It will take about 3 seconds for the profiler to obtain one profile of Doppler velocity power spectra and will record about 20 profiles per minute.

GPM MC3E Operating parameters for 2.875 GHz and 449 MHz (S-band and UHF) profilers

Parameter	**S-band Profiler**		**UHF Profiler**
Frequency	2.875 GHz		449 MHz
Wavelength	10.4 cm		66.8 cm
Peak Power	380 W		6 kW
Antenna	1.2-m shrouded dish		Collinear coaxial array
Beamwidth	2.5°		9°
Mode	**Precipitation**	**Attenuated**	**Vertical air motion**
Interpulse period (μs)	110	110	110
Unambiguous range (km)	16.5	16.5	16.5
Pulse width (ns)	400	400	1700
Range Resolution (m)	60	60	255
Number of range gates	250	250	60
Max height sampled (km)	15	15	15.3
First range gate (km)			
Number coherent integrations	15	15	96
Nyquist Velocity (m s^{-1})	15.8	15.8	15.8
Number points in spectra	256	256	256
Spectral resolution (m s^{-1})	0.124	0.124	0.124

Number of spectral averages	4	4	1
Dwell time (s)	2	2	3
Number of consecutive profiles per minute	15 (~45 s dwell)	5 (~15 s dwell)	20 (Continuous operation)
Receiver Attenuation (dB)	0	30	0
Min. sensitivity at 2 and 10 km (dBZ)	Approx. -10 and 3	Approx. 20 and 33	TBD
Dynamic range (dBZ)	60	60	60
Max. reflectivity at 2 km before saturation (dBZ)	50	80	TBD

4. ARM radar facility: Need for more than one sampling mode

The wide range of cloud and precipitation atmospheric states (e.g., clear, low-middle-high clouds, shallow and deep convective precipitation and large-scale precipitation) pose a grand challenge on how to best sample the atmosphere in order to achieve the MC3E scientific objectives. The unique capabilities of the profiling and scanning radar systems at the ARM SGP radar facility enable both cloud and precipitation sensing in space. This brings another interesting challenge: How to combine these sensors for optimum sampling during MC3E? The answer is to implement different sampling modes for the radar facility. This approach is not new. For example, the US operational weather radar network (WSR-88D) has established a preset of volume coverage settings (e.g., surveillance, clear air, severe weather) that best serve the mandate of the weather radar network. A similar approach will be used for the first operational scanning cloud radars.

The main conclusion is that there is a need for ***optimization*** of the radar facility in order to address the wide range of MC3E scientific objectives that include documentation of the 3D hydrometeor state in both cloudy/clear and precipitating conditions. In turn, optimization calls for coordinated (among different sensors) sampling strategies and operating modes that change (adaptive sampling) according to a minimum set of radar-viewed atmospheric states. This statement requires the definition of the facility ***heartbeat*** (how fast can the facility operating mode change), the definition of the ***radar-viewed atmospheric state*** and the development of **feature detection algorithms** on first-look radar data in order to identify the current atmospheric state.

The determination of **feature detection algorithm**s is used in Distributed Adaptive Collaborative Sensing (DACS) networks (e.g., CASA) and enables automated, computer-based adapting of the radar sampling strategies to best serve the mandate protocol of the network. This close-loop process is a desirable feature for a facility such as the ARM SGP radar facility, however, time constrains make such an implementation challenging by the beginning of the field experiment (April-May 2011). Furthermore, the computer-based determination of the atmospheric state is, by default, limited compared to the one obtained through an objective analysis of a more comprehensive dataset, detail numerical model forecast output or the expert opinion of a PI at the field. Thus, we recommend that the ARM SGP radar facility develops a preset of scan strategies for the radars and the on-site field scientists will determine the temporal implementation.

For the MC3E field campaign radar sampling modes, a set of three atmospheric states is envisioned:

Clear/Cloudy skies and shallow precipitation conditions: Includes clear sky conditions, non-precipitating cloud layers and broken cloud conditions. Low-level stratiform (drizzle), and shallow convective (warm) precipitation conditions are also included in this category. This atmospheric state is expected to occur an overwhelming fraction of the time at the SGP site.

Deep convective precipitating clouds: Deep (echo tops well above 0°C isotherm) convective clouds (high, elevated reflectivity echoes) with potentially strong dynamics. This is a typical warm season condition that is expected only a small fraction of the time but is expected to provide our best sampling periods for retrievals of convective clouds dynamics and precipitation volume.

Large-scale (stratiform) precipitation: Deep precipitating layer with ice microphysics processes and weak dynamics (radar bright band signature).

In addition to the recommended radar sampling strategies that are designed to best document the 3D hydrometeor state, MC3E scientists would like to have the ability to implement a C-band azimuth sector scan if a research aircraft is conducting in-situ microphysics measurements in the vicinity of the ARM SGP radar facility.

Aircraft mode: If a research aircraft is in the vicinity of the SGP radar facility, and conditions permit racetracks within the area of coverage of the X-band network, a special operational mode for the DOE C-band radar is recommended (wide sector scan). This scan type will satisfy NASA interests as well.

5. DOE ARM SGP Radar Scan Strategies

Here, the scan strategies that the MC3E science team recommends for the C-band radar system, the X-band network, the dual-frequency scanning cloud radar and the profiling radars (MMCR and wind profiler network) are described. The added detail provided here also serves as a more general template for scanning of DOE radar infrastructure after the MC3E.

5.1. C-band polarimetric radar

General sampling mode

The primary mission of the C-band polarimetric radar system is to provide the mesoscale context of precipitation over 100-120 km distances from the radar. During the TWP-ICE, the C-POL in Darwin provided such consistent observations and we have adapted their scan strategy as the general sampling mode for the ARM SGP C-POL. The total time for the volume scan should be between 8-10 min. In addition to the 17 elevation tilts, we recommend an RHI scan over the CF, a low-PRF (0.75 KHz) lowest elevation sweep and 30-45 sec of VPR as part of the general sampling mode.

Operational Parameter			
Scan type	PPI (8-9 min)	RHI (15-20 sec)	VPR (15-30 sec)
Scan angles	360° sweeps at EL: 0.5 1.2 1.9 2.6 3.5 4.4 5.3 6.4 7.8 9.6 11.7 14.3 17.5 21.4 26.1 33.0 42.0	0-90° sweep over the central facility	Vertically pointing, ZDR calibration EL: 90
Scan rate	18°	9°	-
PRF	1.25 kHz (0.75 at 0.5°)	1.25 kHz	1.25 kHz
Range resolution	150 m	150 m	60 m
Nyquist velocity	16.9 ms^{-1}	16.9 ms^{-1}	16.9 ms^{-1}
Number of pulses	64	128	1024
Sensitivity (no integration gain)	-6 dBZ at 15 km	-6 dBZ at 15 km	-2 dBZ at 15 km

The 5.4-cm wavelength ensures that measurements from these systems within precipitation will remain effectively unaffected by complete attenuation/extinction in rain within strong convective cells. These systems offer extended range coverage (~100 km) and high-resolution measurements suitable for detailed profiling and mesoscale-type precipitation studies.

Aircraft sampling mode
If a research aircraft is performing in-situ microphysics racetracks in the vicinity of the CF domain, we would like to have the ability to perform wide azimuth sector scans (90-150°). The proposed scan is similar to the general sampling mode, excluding the RHI over the CF and the VPR. The goal is to reduce the temporal update from 8-10 min to 5 min. This will improve our ability to use the in-situ microphysics to validate/develop C-band retrieval algorithms.

5.2. X-band radar network sampling strategies

The acquisition of the X-band radar network at the ARM SGP radar facility is based on the desire to bridge the observational gap in sensitivity and spatial scales between the dual-frequency scanning cloud radar and C-band polarimetric radar. In most applications (especially in the context of MC3E) the X-band network is expected to have a *supporting role* improving either cloud or precipitation measurements. One noticeable example, where the X-band radar network is expected to have a *leading role* is the retrieval of vertical air motion in deep convective clouds (key scientific objective of the MC3E field campaign). Three sampling modes are recommended for the X-band network.

X-band network mode	**Clear/Cloudy and Shallow precipitation**	**Deep convective precipitation**	**Large-scale precipitation**
Scientific Objectives	Characterize low-level divergence Detect "first" echoes from non-precipitating and shallow convection Characterize cloudiness in all levels	Retrieval of vertical air motion with magnitude more than 2 ms^{-1} in convective cores.	Microphysical retrievals and melting layer studies. Characterization of the horizontal wind field.

The transition from one sampling mode to another will be based on the meteorological data available to the field scientists during MC3E. Some preliminary criteria for selecting the X-band network-operating mode are given in the following table:

X-band network mode	**Clear/Cloudy and Shallow precipitation**	**Deep convective precipitation**	**Large-scale precipitation**
Meteorological criteria	No measurable precipitation by the 2DVD disdrometer No C-band echo above 0 to 5 dBZ at any level in a box 50x50 km around the CF	Measurable precipitation by the 2DVD disdrometer C-band echoes exceed 0 to 5 dBZ at any level in the box 50x50 km around the CF C-band CAPPI's exhibit large horizontal in homogeneity	Measurable precipitation by the 2DVD disdrometer C-band echoes exceed 0 to 5 dBZ at any level in the box 50x50 km around the CF C-band CAPPI's and RHI's indicate widespread detection of melting layer signature

The outlined criteria can only provide average conditions between different X-band network scan strategies and could provide a rough guideline for post-MC3E operations of the X-band network. During MC3E, the presence of the science team at the field implies that the decision will be made using more comprehensive information. To this end, real time display of radar observables of all the ARM SGP radar facility (e.g., CAPPI's at different levels and RHI's over the CF) will greatly improve our ability to make accurate decisions on which sampling strategy best serves the scientific objectives for the MC3E field experiment. <u>If we do not have sufficient information to make an intelligent decision during the field campaign, the deep convective mode will be selected</u>.

Clear/Cloudy sky and shallow precipitation sampling mode

Includes clear sky conditions, non-precipitating cloud layers and broken cloud conditions. Low-level stratiform (drizzle), and shallow convective (warm) precipitation conditions are also included in this category. This atmospheric state is expected to occur an overwhelming fraction of the time at the SGP site. The recommended scan strategy includes a combination of PPI and RHI scans (see table below). The time duration for the clear/cloudy and shallow precipitation sampling strategy should be between 8-10 min. It is highly desirable that sync with the C-band polarimetric radar general sampling mode (e.g., common starting time).

Operational Parameter		
Scan type	PPI (5-6 min)	HS-RHI (2-2.5 min)
Scan angles	360° sweeps at EL: 0.5 1.5 2.5 3.5 4.5 5.5 6.5 8.0 9.0 10.0	0-180° sweeps at six azimuth angles
Scan rate	10.6°	10.6°
PRF	2 kHz	2 kHz
Range resolution	60 m	60 m
Nyquist velocity	16 ms^{-1}	16 ms^{-1}
Number of pulses	192 ~ 10 dB integration gain	192 ~ 10 dB integration gain
Sensitivity (no integration gain)	-10 dBZ at 15 km	-10 dBZ at 15 km

The main objective of the clear/cloudy and shallow precipitation sampling strategy is to support the determination of the 3D hydrometeor structure during cloudy conditions and to provide "first precipitation echo" mapping from shallow cumulus.

Deep convective precipitation sampling mode

This is a typical warm season condition that is expected to occur only a small fraction of time but it is expected to provide our best sampling periods for retrievals of convective clouds dynamics. The main requirements for this scan strategy are:

i) complete in 5-6 min, 360 degree scanning
ii) sample convective clouds top (e.g. 15 km) over the CF,
iii) minimize Doppler velocity aliasing,
iv) high spatial resolution.

Operational Parameter	
Scan type	PPI (5-6 min)
Scan angles * The max scan angle, number of elevations and spacing will be revisited in the fall using a radar simulator	360° sweeps at EL: 0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 14 17 20 25 30 35 40 45 50 55*
Scan rate	24°/sec
PRF** Will be revised, potential to use dual PRT approach	2.5 kHz**

Range resolution	50 m
Nyquist velocity	20 ms^{-1}
Number of pulses	96
Sensitivity (no integration gain)	-6 dBZ at 15 km

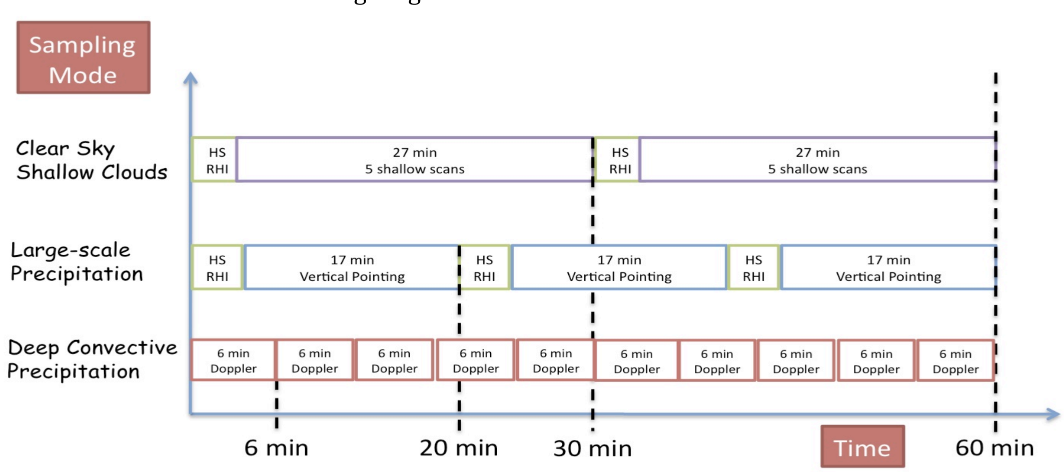
The main objective of the convective precipitation mode is to provide unique insights to the 3D wind structure in deep convective clouds. Thus, its primary objective is to provide 3 radial Doppler velocity components in a 30x30 km box around the CF. The velocity measurements from the X-band network will be augmented with the reflectivity field from the scanning C-band polarimetric radar. Having all three X-bands scan in a 360 full volume will also satisfy the needs of NASA GV.

Large-scale (stratiform) precipitation sampling mode

Operational Parameter		
Scan type	VPR (16-17 min)	HS-RHI (2-2.5 min)
Scan angles	-	0-180° sweeps at six azimuth angles
Scan rate	-	10.6°
PRF	1.5 kHz	2 kHz
Range resolution	30 m (max height~ 18 Km)	60 m
Nyquist velocity	12 ms^{-1}	16 ms^{-1}
Number of pulses	1024	192 ~ 10 dB sensitivity gain
Sensitivity (no integration gain)	-10 dBZ at 15 km	-10 dBZ at 15 km

The main objective of the large-scale precipitation mode for the X-band network is to improve our ability to retrieve microphysics in precipitation in conjunction with the C-band polarimetric radar. During the vertical pointing radar (VPR) sampling periods, Z+V and the entire recorded Doppler spectrum (only mode that we should record the Doppler spectrum) will provide constraint for microphysical inversion. In addition, the HS-RHI mode will provide X-band polarimetric measurements above, in and below the melting layer and thus improve microphysical retrievals.

Some of the RHI scans will be programmed to provide range-height cross-sections over other radar systems during MC3E (e.g., CF, wind profiler sites, NPOL, D3R). In particular, it is desirable to have the southeastern X-band radar HS-RHI will be coordinated with the D3R and NPOL radars over the CF when precipitation is present. The temporal sequences of the X-band network modes during MC3E are shown in the following diagram.



5.3. W/K-band polarimetric cloud radar (SACR)

The W/K-band cloud radar is part of the six dual-frequency scanning, polarimetric (LDR) cloud radar systems of the ARM program for the fixed and mobile sites. The K-band (35-GHz) radar is the primary cloud sensing frequency (most sensitive). The following scan strategies have been tested/evaluated for the ARM scanning cloud radars:

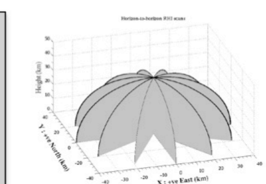
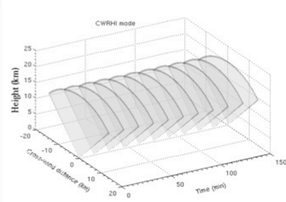
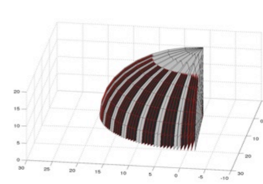
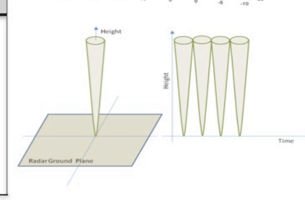
BL-RHI: A volume-imaging scan for mapping the detail 3D cloud structure of boundary layer clouds (0-3 km). It is an azimuth sector (90 degrees) scan centered on the mean wind direction at the boundary layer (BL). The BL-RHI scan is repeated N-time (N:3-5) to provide cloud lifecycle information.

CW-RHI: A volume-imaging scan for slicing high and/or low level clouds as they advect over the CF with the mean horizontal wind flow. It is a horizon-to-horizon cross-wind RHI scan that is repeated for time periods from 15 to 60 min.

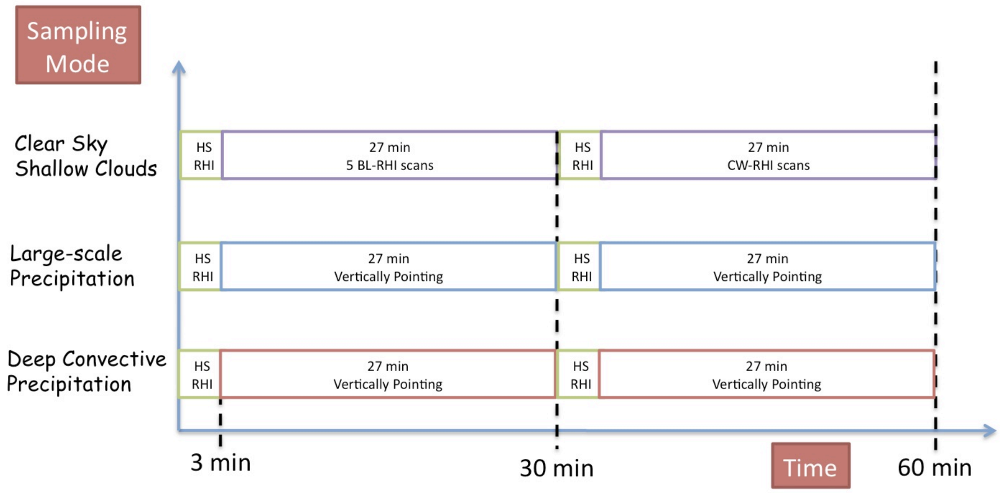
HS-RHI: A sequence of six horizon-to-horizon RHI scans at discrete azimuth angle independent of the wind direction or cloud type. The HS-RHI scan requires 3 min to complete (~30 sec per 180°) and the six slices of the hemispherical sky are used to provide descriptor of the 3D cloud structure. The HS-RHI is repeated every 15 to 30 min to provide a uniform sampling of the cloud state around the ARM sites. The HS-RHI observations can be used to retrieve the horizontal wind field.

VPR: Vertically point mode. During this mode, the recorded radar Doppler spectrum, the differential wavelength radar reflectivity and Doppler velocity measurements will be used to strengthen the retrieval of microphysical retrievals in the overlaying atmospheric column.

Table of SACR operational modes during MC3E

HS-RHI Hemispheric Sky Cross Sections 6 - Horizon-to-Horizon scans Duration: 3 min Repeat: Every 30 min **All-cloud-conditions mode**	
CW-RHI Cross-Wind Range Height Indicator Requires wind direction input Repeat Horizon-to-Horizon scan N-times Duration: 15 min to 60 min **Best scan strategy for high clouds**	
BL-RHI 90° azimuth sector around wind direction. 2° azimuth resolution Duration: 5 min Repeat: 3-6 times (lifecycle) **Best scan strategy for low clouds**	
VPR Vertically pointing mode All modes visit zenith frequently Collection of Doppler spectra Duration: always in rain **Best scan strategy for precipitation**	

During clear skies and cloudy conditions, the W/K-band radar will run sequence of BL-RHI/CW-RHI and HS-RHI scans. During deep precipitation periods, the W/K-band radar will be point vertically and collect dual-frequency Doppler spectra. The temporal sequences of the SACR operating modes are shown in the following figure.



5.4. Wind profilers network and KAZR sampling strategy

For the vertically pointing radar systems, we recommend to maintain their current sampling strategies. Temporal resolution of 2 sec, range resolution of 100 m or better and 256-point FFT Doppler spectra recording is recommended. The four 915-MHz wind profiles will operate according to the set of parameters outlined in the following table.

Parameter	**UHF Profiler**
Frequency	915 MHz
Wavelength	32.8 cm
Peak Power	0.3 kW
Antenna	Phased array
Beamwidth	9°
Mode	**Vertical air motion**
Interpulse period (μs)	120
Unambiguous range (km)	16.3
Pulse width (ns)	2833
Range Resolution (m)	202.4
Number of range gates	75
Max height sampled (km)	15.3
First range gate (km)	0.32
Number coherent integrations	34
Nyquist Velocity (m s^{-1})	20.07
Number points in spectra	128

Spectral resolution (m s^{-1})	0.31
Number of spectral averages	8
Dwell time (s)	5
Number of consecutive profiles per minute	12 (Continuous operation)
Receiver Attenuation (dB)	0
Min. sensitivity at 2 and 10 km (dBZ)	TBD
Dynamic range (dBZ)	60
Max. reflectivity at 2 km before saturation (dBZ)	~ 30 dBZ

During vertically pointing operations the SACR (K/W-band radar) and KAZR (K-band ARM Zenith-Pointing Radar) will have the following configuration.

Operational Parameter	SACR - 94-GHz (W-band) radar	SACR - 35-GHz (K-band) radar	KAZR – 35-GHz (K-band) radar
Scan type	VPR	VPR	VPR
PRF	10 kHz	6.5 kHz	6.5 kHz
Range resolution	30 m	30 m	45 m
Nyquist velocity	8 ms^{-1}	14 ms^{-1}	14 ms^{-1}
Number of pulses	10000	6500	6500
NFFT points	256	256	256
Velocity resolution	6.25 cms^{-1}	10.9 cms^{-1}	10.9 cms^{-1}
Sensitivity (no integration gain)	?? dBZ at 10 km	?? dBZ at 10 km	?? dBZ at 10 km

6. Recommended MC3E Radar Facility Operational Modes

Atmospheric State	***C-SAPR***	***X-SAPR (Network)***	***W/K-SACR***	***KAZR & Wind Profiler Network***
Clear/cloud skies and shallow precipitation	8-10 min heartbeat (surveillance scan +RHI's)	5-6 min shallow surveillance scan and HS-RHI's	Sequence of BL-RHI's (and or CW-RHI's) and HS-RHI	VPR (Doppler spectra recording)
Deep convective precipitating clouds	8-10 min heartbeat (surveillance scan +RHI's)	Convective precipitation scan – Wind retrieval	VPR/HS-RHI (Doppler spectra recording)	VPR (Doppler spectra recording)
Large-scale (stratiform) precipitation	8-10 min heartbeat (surveillance scan +RHI's)	VPR (moments only), bird-bath and HS-RHI's	VPR /HS-RHI (Doppler spectra recording)	VPR (Doppler spectra recording)
Aircraft Mode (only the C-SAPR is affected)	Wide sector azimuth scan (90-150) over the CF	Depending on atmospheric state	Depending on atmospheric state	Depending on atmospheric state